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The Profitability of Households' Solar Power Generation in Finland

Bachelor's Thesis

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Abstract

To achieve the goal to have a proportion of renewable energy corresponding to 20 per cent of total energy consumption set by the EU's Renewable Energy Directive, the amount of renewable energy has to be increased substantially. Finland has mostly invested in wind power and biofuel to meet the requirements. However, solar power has potential to have a bigger part in renewable energy generation, despite Finland's geological location. Germany has successfully increased the amount of renewable energy by using solar power. As Southern Finland receives about the same amount of sunlight as Northern Germany, it makes sense to start considering supporting solar power generation.

In this bachelor's thesis, I will be inspecting the profitability of solar power generation in households in Finland. The calculations will include solar PV systems of two sizes; 3 kWp and 5 kWp. Because solar PV systems are not profitable without support system, I will be introducing Feed-in Tariff –policy from Germany and Tradable Green Certificate –policy from Sweden. The required amount of subsidies will be estimated for both feed-in tariff system and tradable green certificates system. Then I will proceed to compare these two policies to determine which one would be the most efficient one to increase renewable energy production in Finland.

1. Introduction

The European Union's Renewable Energy Directive has set national targets for the proportion of renewable energy. By 2020 the goal is to have a proportion of renewable energy corresponding to 20 per cent of total energy consumption. To achieve this goal, it is essential to implement a support system for renewable energy generation in Finland.

Enough households in Finland are not participating to the generation of electricity from renewable sources. Investing in a solar PV system is not attractive as its costs exceed the possible revenues incurred from selling electricity to energy companies. With a support system, households would be encouraged to participate in the goal to increase renewable energy.

Among other renewable sources, solar power should be considered as a potential source of electricity in Finland. The amount of sunlight Southern Finland receives in a year is close to the amount Northern Germany receives. The Feed-in Tariff system in Germany has accomplished a huge increase in household's solar power generation. With similar kind of environmental conditions, Finland could benefit from encouraging households to start generating electricity from solar power.

Another support system I have included to this paper is Tradable Green Certificate system. Sweden is currently using it to increase the proportion of renewable energy. The goal is to compare FIT and TGC –policies to conclude which one is more efficient in increasing renewable energy with as low additional costs as possible.

2. Electricity Markets and Price Formation

Understanding the principles of electricity markets and how solar power affects them is essential for evaluating feed-in tariff and tradable green certificate policies. The generation of renewable energy is usually intermittent, so either demand or supply has to quickly adapt to the changes in the generation. The demand side being rather inelastic for electricity, it is up to the supply side to use load following power plants as an adaption mechanism.

The electricity prices for household consumers in Finland consist of the price of electric energy (40 %), grid and regional network transmission and distribution costs (30 %), and taxes (30%) (Energiateollisuus ry, 2016).

The supply for electricity in Finland is based on Nord Pool's day-ahead market. In the Nord Pool day-ahead trading system, the participators ask and offer bids. 12:00 CET is the deadline for submitting bids which are then delivered the following day. From 00:00 CET the next day, power contracts are physically delivered hour for hour according to the contracts agreed. (Nord Pool Spot, 2016)

Figure 1 shows that the supply curve has a market merit order; base-load nuclear and coal facilities bid the lowest price. Then CCGT (Combined Cycle Gas Turbine) and other generation are added.

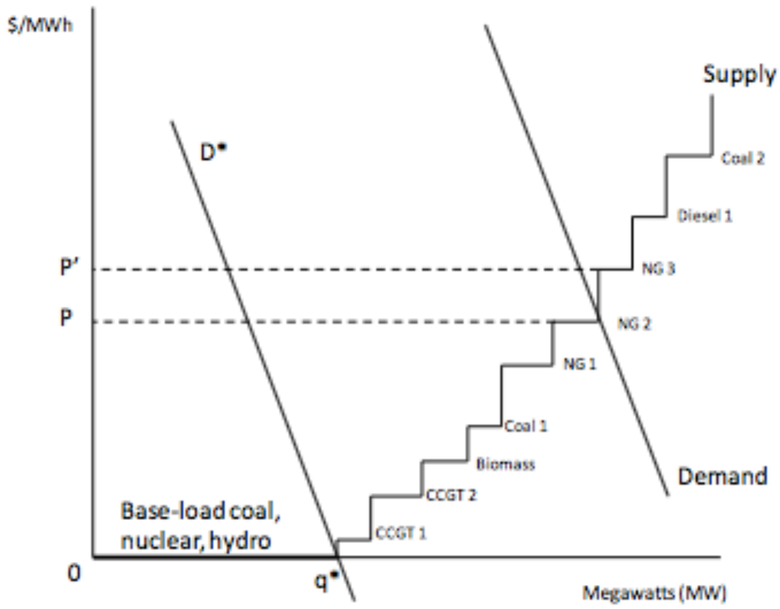


Figure 1. Market Merit Order (Van Kooten, 2011)

When the demand curve D crosses the supply curve, the market price is P, given by the marginal open-cycle natural gas plant (NG 2). If NG 2 was unable to deliver power, NG 3 would then determine the market price, which would now be P'. All electricity generators will receive the price P or P', depending on the ability to deliver power. (Van Kooten, 2011)

When a renewable energy source is introduced to the electricity system as a result of a feed-in tariff or a tradable green certificates, the supply curve shifts to the right by amount $q * q^0$ in the Figure 2. The marginal producer of electricity is now NG 1 instead of NG 2. The increased supply lowers the price from P to P^F. The lower price induces consumers to purchase more electricity, as indicated by the arrow. (Van Kooten, 2011)

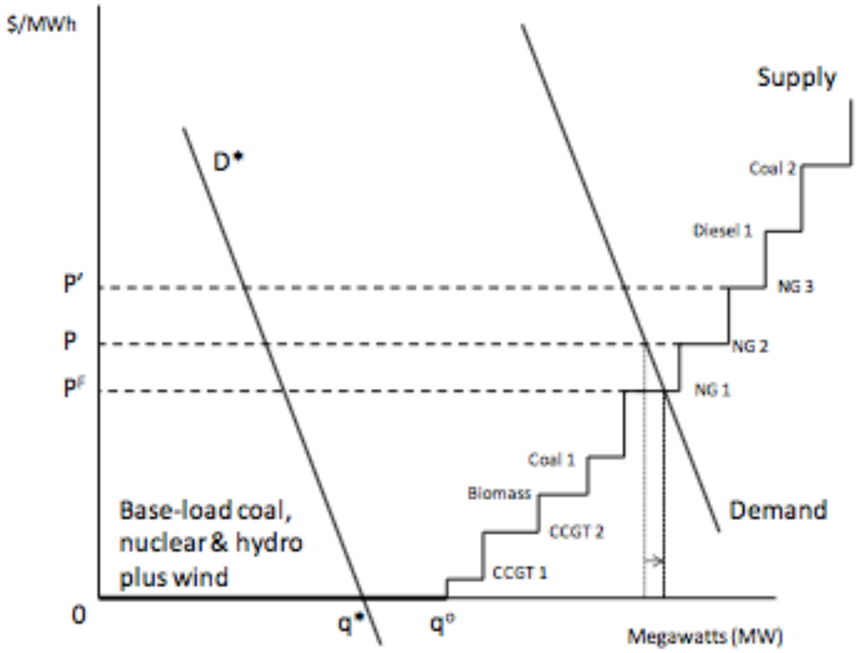


Figure 2. Market Merit Order with Renewable Energy (Van Kooten, 2011)

3. A Support Model in Germany

In year 2000, German adopted an act called The Renewable Energy Sources Act (EEG). The goal is to alter Germany's energy supply from conventional energy sources to renewable ones. The main principle of the act is to provide a fixed remuneration for every kilowatt-hour to anyone generating electricity from renewable energy sources up to 20 years. (BMWi, 2015)

3.1. Feed-in Tariffs

Feed-in Tariff (FIT) is a generation based fixed price incentive, which an independent producer of renewable electricity receives (Chiung-Wen, 2012). It usually takes a form of a total price for renewable production. Another option is to use an additional premium on top of the electricity market price. (Huber, C. et al., 2004) The former option is used in Germany. The "EEG surcharge", which is the difference between the fixed price and the market price for electricity, is passed on to the electricity consumers (BMWi, 2015). Another quality of the feed-in tariff is that the set tariffs decrease annually for new installations (Clean Energy Wire, 2016). The reason for including a degressive element is to acknowledge the development of technology and thereby lower generation costs over time.

The main reason for FIT is to enhance public willingness to install solar PV systems by providing a financial reliability for the producers of renewable electricity (Chiung-Wen, 2012). At the moment, the cost of installing a solar PV system exceeds the revenues from selling the electricity. This makes the investment unprofitable and thus does not promote installation. However, with the implemented FIT -policy, it has become profitable for households to generate solar power in Germany.

When a FIT -policy is implemented, it is necessary that the FIT value is high enough to pay back the investment cost within a reasonable timeframe, such as the lifetime of the solar PV installation.

Starting 2017, Germany will replace feed-in tariffs fixed by the government with auctions. This means that only the renewable installations that have won a tender will receive payments. The aim for this reform is to control how much new capacity is added each year and introduce market-based approach into the support system. This reform, however, will not affect small renewables installations of under 750 kilowatt capacity which means that households will still receive the same feed-in tariffs. (Clean Energy Wire, 2016)

4. A Support Model in Sweden

Sweden's electricity certificate market has existed since year 2003. Since year 2012, Sweden has had a joint market for electricity market with Norway. A joint market will result in a larger number of participants with more cost-effective manner, as the renewable energy production investments will be directed to the most favourable options. (Norges vassdrags- og energidirektorat and Energimyndigheten, 2015)

Sweden has defined a target of increasing renewable energy production by a total of 28.4 TWh, which is about 17 per cent of the total generation of energy in Sweden, from 2012 to the end of 2020. The purpose of this target is to contribute the country's target in relation to the EU Renewable Energy Directive. The EU's Renewable Directive has set binding national targets to ensure that by 2020, 20 per cent of total energy consumption will be from renewable energy in EU.

In Sweden, the market participants who have quota obligation are energy suppliers, electricity consumers who use energy produced themselves (if it exceeds 60 MWh per year), electricity consumers who buy and use electricity from Nordic Pool Spot and energy-intensive industries that are registered by Swedish Energy Agency. (Norges vassdrags- og energidirektorat and Energimyndigheten, 2015) This means that normal households that generate electricity are excluded from the certificate markets. Nevertheless, households will be included in the possible TGC market in this paper.

4.1. Tradable Green Certificates

Tradable Green Certificates (TGC) is a generation based capacity-driven instrument for promoting the installation of renewable energy (Huber, C. et al., 2004). The instrument is a financial asset that can be traded in the electricity spot market. The supplier of renewable energy thus receives the spot price plus the TGC price per MWh. (Vogstad, 2003)

They are usually implemented through government to define targets and obligations on either consumers or electricity suppliers. Once defined, another separate market for renewable electricity is established. The price is then decided based on demand, supply and the quota. (Huber, 2004) The certificates can be obtained in three different ways. First, they can be obtained from own renewable electricity generation. Second, by purchasing renewable electricity and in the same time certificates from other generators. Last, by simply purchasing certificates without purchasing the actual power. (Haas et al., 2011) The compliance period for certificates is 1 year. If the certificate quota is not met within the time period, the obligated has to pay a penalty fee of 150 per cent of the certificate's value.

5. The Profitability of Household Solar Generation in Finland

5.1. Levelized Cost of Electricity

Levelized cost of electricity (LCOE) is the constant price for output incurred from generating electricity. The net present value of all expected lifetime costs from the plant's output is divided with net present value of the plant's lifetime expected power output (kWh). Formally,

$$\sum_{t=1}^{N} q_t \frac{LCOE}{(1+r)^t} = \sum_{t=0}^{N} \frac{C_t}{(1+r)^t} \Rightarrow LCOE = \frac{\sum_{t=0}^{N} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{N} \frac{q_t}{(1+r)^t}}$$

Where C_t is the cost of production at time period t, N is the total amount of periods, r is the interest rate, and q_t is the quantity of production. (Liski, 2016)

Solar PV system	3 kWp	5 kWp
The average consumer electricity price (€/kWh)	0,116	0,116
LCOE (€/kWh)	0,150	0,121

Table 1. The LCOEs of the 3 kWp and 5 kWp solar PV systems

In table 1 I have calculated the LCOE for two solar PV systems of the sizes 3 kWp (kilowatt peak) and 5 kWp. A solar PV system is a power system that generates solar power by the means of photovoltaics. It consists of all the necessary components to produce solar power, such as solar panels, an inverter and other accessories to set up the system. A system of size 3 kWp generates 2684 kWh per year and the 5 kWp system generates 4474 kWh per year. The interest rate used to calculate the LCOEs is 2 per cent, which is based on the interest rate of 10-year government bond in Finland plus a small risk premium. These calculations are made based on the technological assumptions explained in a master's thesis written by Kahola, which are mentioned in the appendix.

LCOE presents a basis of comparison for weighted average costs of different power generation technologies (Kost et al., 2013). The LCOE is above the average consumer electricity price for both systems. This means that electricity generated from solar power is not yet as competitive as electricity from other sources, notably nuclear power. Nevertheless, in contrast to the increasing energy prices for fossil and nuclear power sources, LCOE of renewable energy technologies have been decreasing over time (Kost et al., 2013).

5.2. The Benefits of Solar Power Generation

5.2.1. Quantity of Solar Power Generation

The main financial benefit from generating own electricity comes from saving the costs of buying electricity outside. The main savings comes from not needing to pay transmission costs nor taxes.

Depending on the size of the solar PV installation, a household producer is able to either consume the produced electricity or sell the excess electricity to an energy company. It is estimated that a 3 kWp solar PV system generates about 1208 kWh excess electricity per year, whereas a 5 kWp one generates 2684 kWp.

The average selling price of electricity for year 2016 that households receive is 0,0303 €/kWh, which includes the commission price of 0,0024 €/kWh (Fortum, 2016) paid to the electricity company. The low price indicates that without any kind of incentives or subsidies, a household should only produce electricity as much as it can consume itself. Thus, solar PV systems should have smaller capacities to avoid any excess electricity. However, the approach to generate less RES-E (electricity from renewable energy sources) doesn't support the goal to increase the amount of renewable energy in the total energy consumption.

5.2.2. Usage Cost

The installation of a solar PV system has an effect on the value of the building. Harjunen and Liski (2014) examine in their paper the lifetime cost of heating in a single-family house of average size in Finland (170 m2) with average annual need for energy (130 kWh/m2). The usage cost is calculated in figure 2 using the present value method for a 25-year time period with discount rates 5 and 15.

Households that generate solar energy have lower usage cost, as the marginal cost for electricity generation is zero. The saving in usage cost raises the value of the building, and same time the willingness to pay for it. The following equations express the effect of usage cost on the price of a building:

$$Q^D = \alpha_0 - \alpha_1 p - \gamma C$$

Q^D is the quantity demanded and p is the price. C measures the usage cost over the relevant life time with discount factor $\delta < 1$. When $\alpha_1 = \gamma$, there is no myopia involved and the change in usage cost transfers completely to the asking price. When $\Delta Q^D = 0$,

$\Rightarrow p = \frac{\alpha_0}{\alpha_1} - \frac{\gamma}{\alpha_1} C$, and $\Rightarrow p = \frac{\alpha_0}{\alpha_1} - 1 * C$.

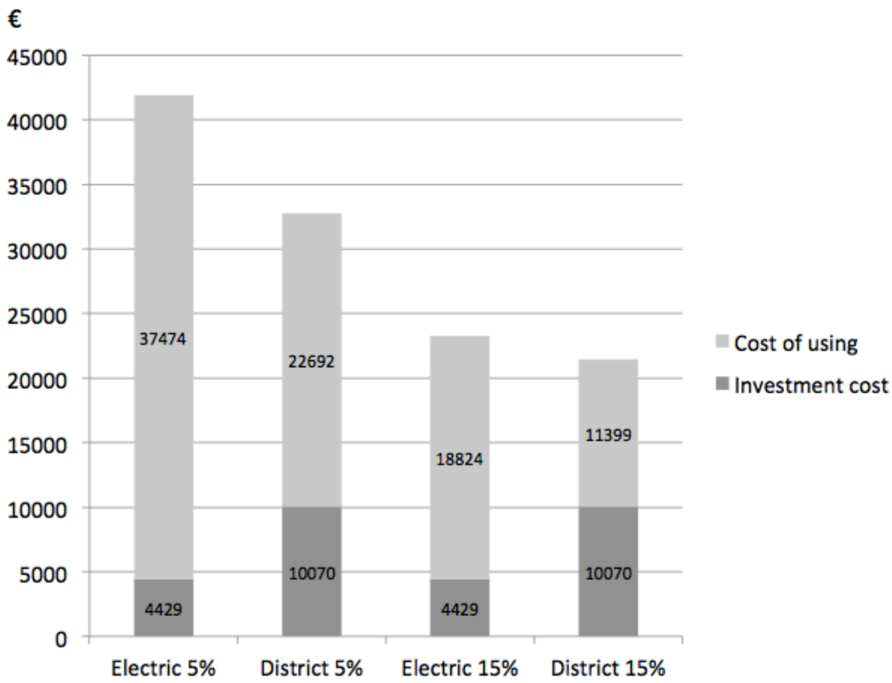


Illustration of the life-time cost of the heating systems for an average house in Finland in 2013 euros. Source for the investment costs: Building Information Foundation RTS, survey 2010. Cost of using the technologies is calculated from the contract prices in Table 1, using 25 years of lifetime and the reported discount rates.

Figure 2. The usage costs of electric and district heating (Harjunen et Liski, 2014)

This means, that if the usage cost decreases ($\Delta C < 0$), the price p (and so the value of the building) increases. Of course one must take in to account, that the solar power generation cannot completely replace the electricity bought outside and the annual need for energy used in the paper written by Harjunen and Liski differs 4100 kWh/per annum from this paper's assumed annual energy consumption. However, this equation could be applied, when calculating the effect more precisely.

5.3. Profitability Measures

The following calculations are based on the financial and technological assumptions expressed in a master's thesis written by Kahola (2015). As there hasn't been a much change in the prices of solar PV panels within a year, it is reasonable to use the information as a base for profitability calculations. The assumptions are introduced in the appendix.

The profitability of solar PV installations is evaluated with return on investment (ROI), real rate of return and net present value (NPV). Based on the calculations, without feed-in tariffs, investment subsidies or tradable green certificates, generating electricity from solar PV panels isn't profitable.

Solar PV system	3 kWp	5 kWp
Return on investment	- 37 %	- 34 %
Real rate of return	- 50 %	- 48 %
Net present value	- 2 992 €	- 3 964 €

Table 1. Profitability without any governmental support

Return on investment measures the amount of return on an investment relative to the investment cost. The result is expressed as a percentage, which makes it comparable to other investments. However, it doesn't take into account the time value of money, which is why real rate on return is also used as a metric to evaluate profitability.

Net present value includes all costs and revenues incurred by a solar PV system. So that the time value of money is included, the cash flow is then discounted to this moment. In the following calculations, net present value of 0 € or more with a 2 % discount rate is considered to be profitable.

5.3.1. Feed-in Tariffs

In the table 2 I have calculated how high the feed-in tariff has to be for a solar PV system to be profitable from household's perspective. It seems that the FIT has to be higher for a smaller system to be profitable, if the household is not able to consume or store all the generated solar energy.

Solar PV system	3 kWp	5 kWp
Feed-in tariff (€)	0,164	0,110
Difference to the average consumer electricity price (€)	+ 0,048	- 0,006

Table 2. The required price of FIT

The FIT required for a 3 kWp wouldn't be efficient way to encourage solar PV installations as it is higher than the average consumer electricity price. It would be then more efficient to set the FIT to be 0,110 €/kWh, and households would purchase larger systems.

Below is a figure, which portrays the development of FIT prices in Germany for the years 2000-2016. The prices have fallen substantially during the years, and it seems that the required FIT price in Finland is in the same level as the actual price is in Germany.

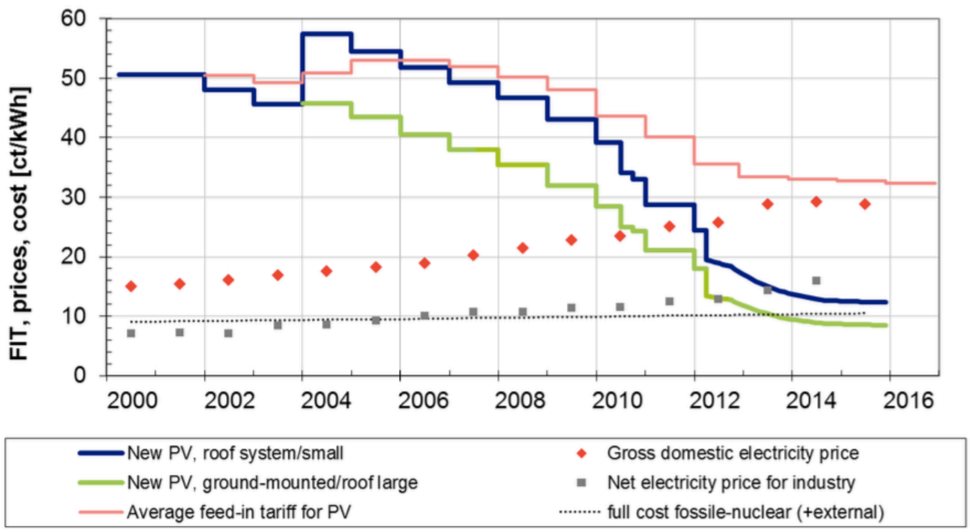


Figure 3. FIT prices in Germany (ct/kWh) in time period 2000-2016 (Wirth, 2016)

5.3.2. Tradable Green Certificates (TGC)

As with feed-in tariffs, tradable green certificates price is also lower when the size of a solar PV system is 5 kWp. As tradable green certificates include the whole generation of solar energy, not only the electricity sold to energy companies, the prices of TGC are naturally much lower compared to FITs. However, the government sets a quota instead of a price for tradable green certificates. The price is then formed in the TGC market.

Solar PV system	3 kWp	5 kWp
TGC (€)/ kWh	0,060	0,048

Table 3. The required price for TGC

For comparison, I have included Figure 3 to illustrate prices of certificates in different European countries for years 2002-2008. In Sweden, where the quota was 16,9 % in year 2010, the price per kWh has been the lowest (varying from 0,02 €/kWh to 0,04 €/kWh). I have collected the information of TGC policies in Table

4. The trend seems to indicate that countries with low quotas usually have higher TGC prices.

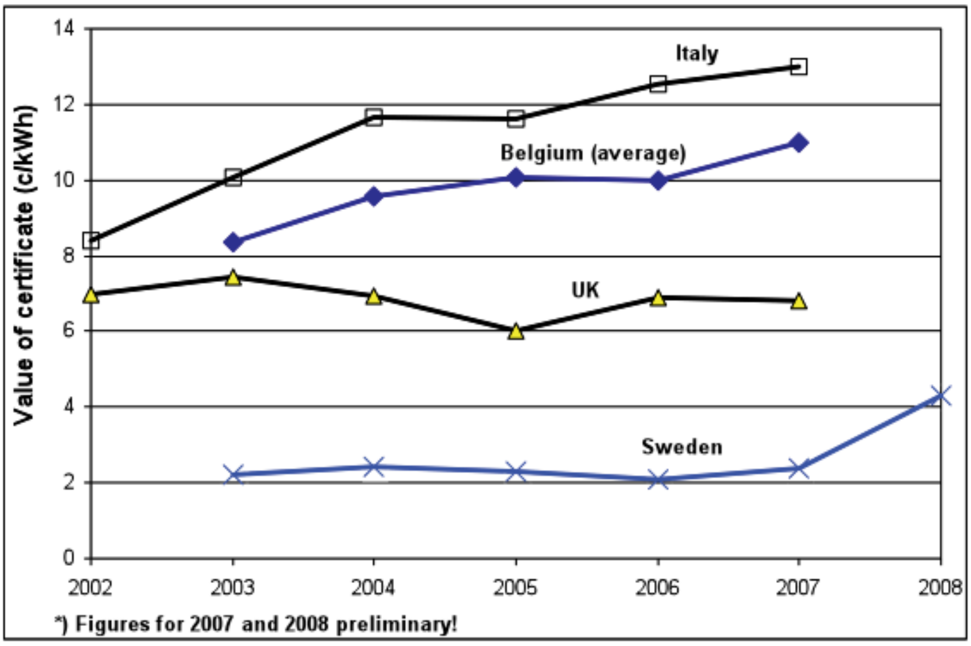


Figure 3. Value of certificate in different European TGC markets (Haas et al, 2009)

Country	UK	Belgium (Flemish)	Belgium (Wallon)	Italy	Sweden
Period	Start 2002	Start 2002	Start 2002	Start 2001	Start 2003
Obligation	3% in 2003 10.4 % in 2010	1,2 % in 2003, increasing up to 6 %	3% in 2003, increasing up to 12 % 2010	2 % in 2002, increasing annually by 0,35 %	7,4 % in 2003 16,9 % in 2010

Table 4. TGC –policy in different European countries (Haas et al, 2009)

In most TGC –policies, the obligation falls on the energy suppliers. In Sweden, the quota obligations also include electricity consumers who consume over 60 MWh/year their own produced energy. (Norges vassdrags- og energidirektorat and Energimyndigheten, 2015) As households' energy consumption is on much lower level, they are excluded from the TGC market.

6. The Efficiency of the Support Models

In this section, I will be addressing the efficiency of FIT and TGC –policies nationwide. Nations often include renewable energy from different sources and all energy producers, not just households. Thus it is more sensible to examine the policies in a larger perspective.

The consensus of the most efficient support policy has not yet been reached. However, it seems that most scientific studies favour the FIT -policy. These different studies evaluate the policies based on the incurred additional costs and the growth of RES-E generation.

6.1 Theoretical Modelling of the Support Policies

Menanteau et al. examine the policies from a theoretical and practical point of views. With FIT –policy, producers have an incentive to produce the amount of energy so that the marginal cost of producing equals the feed-in tariff. This is portrayed in the Figure 4. When the feed-in tariff is P_{in}, the generated amount is Q_{out}.

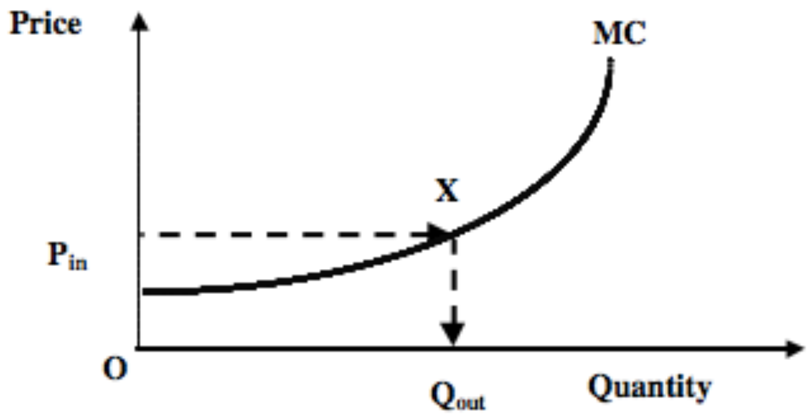


Figure 4. Feed-in tariffs (Menanteau et al., 2003)

Of course, all producers receive the same FIT regardless their marginal production costs. The difference in costs leads to the attribution of economic rent. The cost of reaching the objective is $P_{in} x Q_{out}$.

The TGC –policy favours the most efficient technologies. As producers have different marginal production cost curves, tradable green certificates enables quotas to be allocated in an efficient way. If every producer had the same obligation as others, different marginal costs would incur and thus would increase inefficiency. (Menanteau et al., 2003)

The operation of green certificate markets is portrayed in Figure 5. Two producers, A and B, have different marginal cost curves. Producer A has higher marginal production costs than producer B has. By trading certificates, A limits their production to Q_A and purchases certificates at the equilibrium price p to reach the target q. Producer B increases production to Q_B, and sells the surplus certificates at the price p. The possibility of trade reduces the cost of achieving overall objective ($Q = Q_a + Q_b = 2q$), shown by the shaded area. (Menanteau et al., 2003)

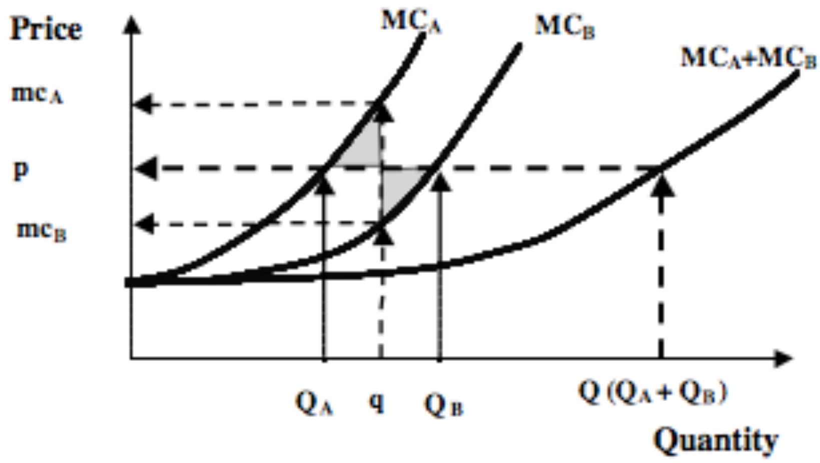
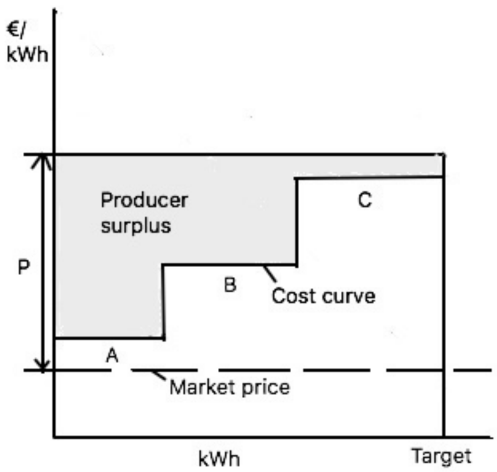
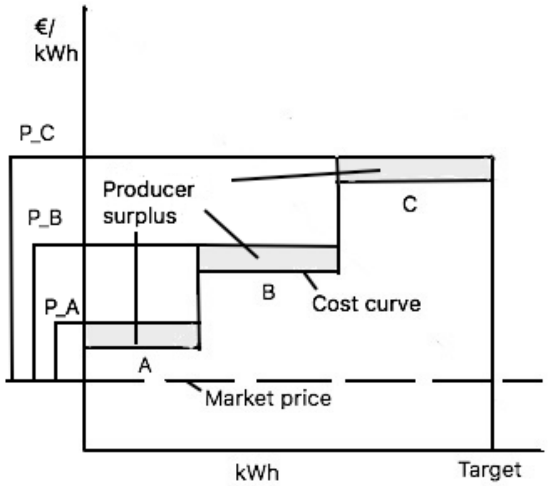


Figure 5. Operation of green certificate markets (Menanteau et al., 2003)

Haas et al. explain that the acceptance of support policy by consumers and investors is relevant. Thus it is important to analyse what are the additional costs imposed on electricity consumers, when a support policy is implemented. The objective is to minimise the additional costs. The direct costs that stem from implementing the system consist of the producer surplus, the generation costs minus the revenues from the sale in the conventional electricity market. It is also possible to subtract the avoided external costs, if they can be determined.

The producer surplus under TGC and FIT –policies is portrayed separately in the figures below. The cost curve is assumed to be steep, which indicates that some RES-E technologies are more efficient than others. This causes some renewable electricity generation to have lower costs than the others. This has the same logic as the principle of market merit order.





Figures 6 and 7. Producer surplus under TGC (left) and FIT (right) –policies when the cost resource curve is steep (Haas et al., 2011)

In Figure 6, the marginal price of the most expensive technology sold, corresponding to the target, determines the price for TGC. Thus, a RES-E generator would receive the price of TGC (i.e. P) and the market price. The shaded area portrays the surplus, which producers receive. From the figure one can see that a high uniform price will result in windfall profits for low-cost technologies. High windfall profits result in higher additional costs to the electricity consumers, who will in the end pay them.

In Figure 7, Haas et al. have used technology-specific premium feed-in tariffs instead of normal feed-in tariffs. Now the producer surplus is considerably smaller, opposed to the surplus under the TGC –policy. With normal feed-in tariffs, the figure would look essentially the same as with TGC –policy (if government decided to also support the most expensive RES-E producers). Then the producer surplus would theoretically be identical as under the TGC –policy. (Norges vassdrags- og energidirektorat and Energimyndigheten, 2015.)

6.2. Evaluating the Impact of the Support Models

The support of incentive programmes is vital to promote electricity generation from renewable sources. RES-E generation is not yet efficient enough to develop independently as long as the negative externalities resulting from conventional energy sources are not internalised. However, during the last 20 years, these support systems have made it possible for RES-E technology to become more competitive with conventional technologies. It is important to compare the different support systems to achieve the highest possible benefit from the additional costs these systems impose on electricity consumers. The comparison will be done based on the incentive to stimulate renewable electricity generation, incentive to lower generation costs and incentive to innovate.

One of the reasons why FIT –policy has stimulated electricity production from renewable sources is the prospect of obtaining high return on investment offered by relatively high prices levels. With fixed and high prices, the market risk is non-existent to the investors. Conversely to the FIT –policy, the support mechanism for renewable energy development are related to electricity price changes. (Menanteau et al., 2003) This gives more volatility to the prices of green certificates, and consequently imposes a market risk to the investors. However, market risk could be reduced by including a floor and a ceiling price to control the volatility of the certificate prices.

Feed-in tariffs have been proved to be costly in terms of subsidies based on the experiences in Germany. When feed-in tariffs are not technology-specific, it can be hard to avoid causing excessive amount of windfall profit to the RES-E generators. The resources would then be allocated inefficiently because of the lack of market competition and the differential renewable electricity generation costs. However, Germany has incorporated a decreasing element based on the level of technology. This limits the surplus to the producers.

Another weakness of feed-in tariffs is the absent incentive to lower the cost of generating electricity from renewable resources. With degressive feed-in tariffs that anticipate progress, the profits can be shared in a more equitable manner. On the contrary, green certificates provide an incentive to lower costs. First, the electricity produced from renewable sources is sold at the market price, which tends to be falling due to deregulation and increased competition. Second, the producers of renewable electricity have the pressure of lowering costs due to the green certificate market. (Menanteau et al., 2003)

Haas et al. and Menanteau et al. both have the same views regarding the administration costs these support systems cause. A FIT –policy can be easily implemented and revised to account for new capacities (Haas et al., 2011). Menanteau et al. also add that administration costs, such as project preparation and selection procedure) are usually less expensive than creating a national trading scheme.

Another important quality of a support system is whether it promotes the incentive to invest in research and development of the electricity generation. In the case of feed-in tariffs, the RES-E generators benefit from the entire surplus resulting from technological progression. (Menanteau et al., 2003) As the marginal cost is reduced due to the progression, the marginal revenue rises and encourages investing more heavily on R&D. However, the profits can be controlled by including a degressive element into the feed-in tariff.

Because the TGC –policy relies on trade market to allocate the certificates to the most efficiently used resources, it tends to promote the most inexpensive energy sources. This makes the policy to be one of the most economical support systems, which makes it attractive in the economical point of view. Nevertheless, this might become a disadvantage in a long-time period, as it might prevent promising, but costly, technologies from receiving investments. (Menanteau et al., 2003)

7. Future Prospects

As there isn't yet a support system similar to FIT or TGC –policies in Finland, there might be a lot of unused potential to develop more efficient technology. Germany has already showed how an all-inclusive support system encourages companies to invest more in research and development. The investments have bore fruit as the prices of the solar PV systems have decreased enormously over the years. Finland could benefit from the German technology, but it is important to encourage domestic production to achieve sustainable economic growth.
Another thing to consider is the storing of electricity. Because electricity from renewable sources is intermittent, it is essential to invest in the development batteries. Right now the batteries used to store electricity are expensive and not realistically obtainable for households. However, if the storing technology improves, it would mean more stable availability of RES-E, which in turn would lessen the market risks, such as electricity price volatility and the intermittent supply of RES-E.

Higher self-sufficiency of electricity could be a goal for Finland. Then the supply of electricity would not have to be as dependent on the neighbour countries as before. This would give more stability and independency to the Finnish electricity markets, which would show in the lower electricity prices.

8. Conclusions

Based on the calculations, households' generation of solar power is not profitable without any kind of support model. The main benefit from generating own electricity is saving in the costs of buying electricity outside. Another benefit is the decrease in usage costs, which increases the value of the building. The incurring costs from the electricity generation however exceed the revenues received from selling the excess electricity. It would be more profitable to support larger 5 kWp solar PV systems as the required prices for both FIT and TGC are lower than in the 3 kWp system. The required prices for TGC are remarkably lower than for FIT. This can be explained as the fact that the TGC –policy includes all of the RES-E generated, while FIT –policy only applies to the RES-E sold outside the household.

The LCOE for solar power is above the average consumer electricity price. This means that solar power isn’t yet as competitive as other electricity sources, notably nuclear power. Implementing a support system should encourage investing more into research and development, which in turn could lead to more efficient and competitive technology.

Theoretically, TGC –policy should be more favourable option, as it is market-based and allocates the certificates effectively to the most competitive RES-E generators. Nevertheless, it seems that FIT –policy has succeeded in increasing the renewable electricity generation and giving incentive to invest in potential technology. This has come with a high price, because the FIT -policy hasn’t been technology-specific in Germany. To avoid high additional costs, premium feed-in tariffs should be used to cut the costs down.

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Appendices

Appendix A

This study uses the financial and technical assumptions expressed in a master's thesis written by Kahola (2015).

Technological assumptions

	The size of a system	
	3 kWp	5 kWp
Solar PV panels		
Life time	25 years	25 years
Yearly generation of electricity	2684 kWh	4474 kWh
Yearly decrease in power	0,5 %	0,5 %
Inverter		
Life time	12,5 years	12,5 years
End usage of the electricity		
For own consumption	55 %	40 %
For selling	45 %	60 %

Appendix B

Investment costs

Solar PV system	3 kWp	5 kWp
The price of a system	(€)	(€)
Solar PV system (including VAT 24%)	4950	7100
Planning and installation	1 650	1 950
Tax credit	-643	-778
Total cost		
Without tax credit	6 600	9 050
With tax credit	5 958	8 273

Solar PV system	3 kWp	5 kWp
The cost of replacement inverter (€)	1133	1333

Appendix C

Financial assumptions

	Value	**Source**
Discounting factor	2 %	
The average consumer electricity price	0,116 €	Energiavirasto (2016)
The price for electricity sold outside	0,0303 €	Energiavirasto (2016)
Tax rate on revenue	0 %	Verohallinto (2016)
Residual value	0 €	

Appendix D Cash flows for a 3 kWp Solar PV system

ear	0	1	2	3	4	5	6	7	8	9	10	11	12
vestment costs													
lar PV system	-3992												
AT 24 %	-958												
anning and installation	-1650												
x credit	643												
eplacement inverter													
evenues/Savings													
vings in electric bill		171	170	169	169	168	167	166	165	164	164	163	162
ectricity sold to grid		37	36	36	36	36	36	36	35	35	35	35	35
early cash flow													
ominal	-5957	208	207	206	205	204	203	202	201	200	199	198	197
iscounted	-5957	204	199	194	189	184	180	175	171	167	163	159	155
umulative cash flow													
ominal	-5957	-5749	-5543	-5337	-5132	-4929	-4726	-4525	-4324	-4125	-3926	-3729	-3532
iscounted	-5957	-5753	-5555	-5361	-5172	-4988	-4808	-4632	-4461	-4294	-4131	-3972	-3817

Year	13	14	15	16	17	18	19	20	21	22	23	24	25
Investment costs													
Solar PV system													
VAT 24 %													
Planning and installation													
Tax credit													
Replacement inverter	-1133												
Revenues/Savings													
Savings in electric bill	161	160	160	159	158	157	156	156	155	154	153	152	152
Electricity sold to grid	34	34	34	34	34	34	33	33	33	33	33	33	32
Yearly cash flow													
Nominal	-937	195	194	193	192	191	190	189	188	187	186	185	184
Discounted	-725	147	144	140	137	134	130	127	124	121	118	115	112
Cumulative cash flow													
Nominal	-4469	-4275	-4081	-3889	-3697	-3506	-3316	-3128	-2940	-2753	-2567	-2382	-2198
Discounted	-4542	-4395	-4251	-4110	-3974	-3840	-3710	-3583	-3459	-3338	-3220	-3105	-2992

Appendix E Cash flows for a 5 kWp Solar PV system

Year	0	1	2	3	4	5	6	7	8	9	10	11	12
Investment costs													
Solar PV system	-5726												
VAT 24 %	-1374												
Planning and installation	-1950												
Tax credit	778												
Replacement inverter													
Revenues/Savings													
Savings in electric bill		207	206	205	204	203	202	201	200	199	198	197	196
Electricity sold to grid		81	81	81	80	80	79	79	79	78	78	77	77
Yearly cash flow													
Nominal	-8272	289	287	286	284	283	282	280	279	277	276	275	273
Discounted	-8272	283	276	269	263	256	250	244	238	232	226	221	215
Cumulative cash flow													
Nominal	-8272	-7983	-7696	-7410	-7126	-6843	-6561	-6281	-6002	-5725	-5449	-5174	-4901
Discounted	-8272	-7989	-7713	-7443	-7181	-6924	-6674	-6430	-6193	-5960	-5734	-5513	-5298

Year	13	14	15	16	17	18	19	20	21	22	23	24	25
Investment costs													
Solar PV system													
VAT 24 %													
Planning and installation													
Tax credit													
Replacement inverter	-1333												
Revenues/Savings													
Savings in electric bill	195	194	193	192	191	190	189	189	188	187	186	185	184
Electricity sold to grid	77	76	76	75	75	75	74	74	74	73	73	72	72
Yearly cash flow													
Nominal	-1061	271	269	268	266	265	264	262	261	260	259	257	256
Discounted	-820	205	200	195	190	186	181	177	172	168	164	160	156
Cumulative cash flow													
Nominal	-5962	-5692	-5423	-5155	-4888	-4623	-4359	-4097	-3836	-3576	-3317	-3060	-2804
Discounted	-6118	-5913	-5713	-5518	-5328	-5142	-4961	-4784	-4612	-4444	-4280	-4120	-3964